

Application of Satellite SAR Imagery in Mapping the Active Layer of Arctic Permafrost

Final Report

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This is a joint project with Dr. Shusun Li from the Geophysical Institute, University of Alaska Fairbanks.

1. Objective of the Proposed Research

The objective of this project is to map the spatial variation of the active layer over the arctic permafrost in terms of two parameters:

- (i) timing and duration of thaw period
- (ii) differential frost heave and thaw settlement of the active layer

To achieve this goal, remote sensing, numerical modeling, and related field measurements are required. Tasks for the University of Colorado team are to:

- (i) determine the timing of snow disappearance in spring through changes in surface albedo
- (ii) simulate the freezing and thawing processes of the active layer
- (iii) simulate the impact of snow cover on permafrost presence

2. Accomplishments

2.1. Snowmelt and surface albedo

Spatial and temporal variations of surface albedo on the North Slope of Alaska were investigated using both ground-based tower measurements and satellite remote sensing data. We use ground-based measurements of incident and reflected solar radiation at several stations along the Dalton Highway over the period 1985 – 1998 to determine in situ surface albedo. We obtained AVHRR-derived surface albedo from AVHRR Polar Pathfinder products, available from the National Snow and Ice Data Center (NSIDC), using a modified cloud mask. AVHRR-derived surface albedo agrees closely with in situ measurements. Results from this study indicate that surface albedo varies from greater than 0.9 for snow-covered land surface under overcast conditions to less than 0.1 for wet tundra land surface. Five distinct temporal periods are discerned, based on seasonal variations of surface albedo: *winter stationary, spring snowmelt, post-snowmelt, summer*

stationary, and *autumn freeze-up periods*. Spatially, we divide the North Slope into three zones based on patterns of seasonal variation in surface albedo. A *Mountain Zone* is along the ranges and slopes of the Brooks Range with elevations above 1000 m. When compared with the other two zones, surface albedo in this zone is the lowest in winter, varying from 0.4 to 0.7, and relatively high in summer, from 0.15 to 0.2. The *Foothills Zone* is along the foothills of the Brooks Range with elevations from 300 m to 1000 m. Surface albedo is relatively high in this zone in winter (0.8) and the highest in summer (0.2). Surface albedo in this zone changes very rapidly from 0.8 to 0.2 within a couple of weeks in spring. The *Coastal Zone* is along the Arctic coastal plain, with elevations lower than 300 m. Coastal zone surface albedo is the highest in winter (>0.8) and the lowest in summer (<0.15). This study suggests that the heat island effect in the vicinity of Barrow is very minimal. Progressive earlier snow cover disappearance at the Barrow National Weather Service station may be an indication of regional spring warming. This study also suggests that snow surface albedo in land surface models should be treated differently for snow at high latitudes as compared with snow in middle latitudes, especially during winter months.

2.2 Active Layer Modeling

Another important component of the proposed research is to model the active layer processes and the thermal regime of permafrost to help to interpret the INSAR results of differential deformation of the active layer. During the past year, we conducted the following modeling work.

Variations in thickness of the active layer over permafrost have a significant impact on tundra ecosystems, greenhouse gas fluxes between the polar soil and the atmosphere, surface geomorphological processes, near-surface hydrology, and thermal regime of permafrost. The thaw depth has also often been represented as an indicator of climatic change. Active layer measurements under natural conditions near Barrow, Alaska have been conducted sporadically from the early 1960s to the present. This research demonstrates that the impact of air temperature, especially thawing index, and soil moisture content on the active layer thickness through modeling. A one-dimensional heat transfer model with phase change was applied. All model input parameters were obtained from field measurements at Barrow, Alaska. Calculated thaw depths fall within a very reasonable range of field measured thaw depth. The validated model was used to conduct a series of sensitivity studies. Some results show that for a constant soil moisture content, the active layer thickness primarily depended upon the thawing index of air temperature. For constant thawing index, changes in seasonal snow cover, freezing index and mean annual air temperature almost have no effect on the seasonally thawing processes and thaw depth almost entirely depended upon soil moisture conditions. Variations of the active layer thickness predicted by the model will also be presented using daily air temperature and snow depth on ground measured by the National Weather Service at Barrow, Alaska for the period from 1947 through 1994. The calculated thaw

depths will also be compared with historical field measurements near Barrow, Alaska.

2.3. Numerical Simulations on the Influence of Snow Cover on the Occurrence of Permafrost

The impact of snow cover on permafrost can be significant due to the high albedo, relatively higher emissivity, low thermal conductivity of snow, and latent heat of fusion of snowmelt. The net effect of snow cover on the ground thermal regime depends on the timing, duration, thickness, structure, and physical and thermal properties of snow cover. It has repeatedly reported that snow cover is a dominated factor determining the presence or absence of permafrost in the discontinuous and sporadic permafrost regions. For example, the temperature at snow-soil interface by the end of winter, the well-known BTS (bottom temperature of snow) method, has been used to detect the existence of permafrost in European alpine regions when the maximum snow depth is about 1.0 m or greater, while a critical snow thickness of about 50 cm or greater could prevent permafrost development in eastern Hudson Bay, Canada. Further investigation on the issue of snow cover and ground thermal regime is definitely needed to improve our understanding of the physical processes involved.

The objective of this study is to investigate the impact of snow cover on presence or absence of permafrost in cold regions through numerical simulations. A one dimensional heat transfer model with phase change and snow cover routine is used to simulate energy exchange between deep soils and the atmosphere. The model has been validated against the in situ data in the Arctic and the results agree well with observations. The baseline model inputs are as follows: mean annual ground surface temperature is set at 0EC with amplitude of 20EC. Soil bulk density is set at 1400 kgm^{-3} with soil water content of 35% by mass. Snow density is 250 kgm^{-3} with its thermal conductivity of about $0.26 \text{ Wm}^{-1} \text{ K}^{-1}$. The lower boundary is set at 75 m below the ground surface with constant heat flux boundary condition. Firstly, the model is run without snow cover until it reaches thermal equilibrium. Due to the effect of thermal offset, permafrost develops with the mean annual temperature at the permafrost surface of about -3.1°C , i.e., the thermal offset value for this case. Then, the model is run with snow cover until the model reaches thermal equilibrium. The maximum snow depth varies from 10 cm to 120 cm with an increment of 10 cm and the snow cover onset date varies from October 1 to late January of the following year with an increment of 15 days. The initial condition used for these runs is the equilibrium temperature profile obtained from model output with no snow cover.

The simulation results indicate that both snow depth and the onset date of snow cover establishment are important parameters for presence or absence of permafrost. For permafrost cases, early snow cover establishment can make permafrost disappear even though with a relatively thin snow cover, while permafrost may survive when snow cover starts after the middle of December even though snow thickness can reach to more than 1.0 m. This effect of snow cover on the ground thermal regime can be explained with

reference to the pattern of seasonal temperature variation. Early snow cover establishment would enhance the insulating impact over the entire cold season, thus warming and eventually thawing permafrost. While the insulating effect would be reduced substantially when snow cover starts relatively late and snowmelt in spring is a huge heat sink, a very favorable combined condition for permafrost existence.

3. Publications: There are four (4) peer reviewed journal articles, two (2) conference papers, and numerous abstracts and conference presentations generated out from this project.

3.1. *Peer reviewed journal publications:*

- [1]. **Zhang, T.**, T. Scambos, T. Haran, L. D. Hinzman, R. G. Barry, and D. L. Kane, 2003. Ground-based and satellite-derived measurements of surface albedo on the North Slope of Alaska, USA, J. Hydrometeorology, (in press).
- [2]. Ling, F. and **T. Zhang**, 2002. A two-dimensional heat transfer model for atmosphere-land system in the lake-dominated Alaskan North Slope, Journal of Xijiang University, 22:1-7.
- [3]. **Zhang, T.**, Roger G. Barry, and W. Haeberli, 2001. Numerical simulations of the influence of the seasonal snow cover on the occurrence of permafrost, Norwegian Journal of Geography, 55(4), 261-266.
- [4]. **Zhang, T.**, R. G. Barry, and R. L. Armstrong, 2001. Application of remote sensing techniques to frozen ground study, Progress in Physical Geography, (in press).

3.2. *Conference Proceedings Publications:*

- [1]. **Zhang, T.**, T. Haran, and T. Scambos, Spatial and temporal variations of surface albedo and snowmelt in northern Alaska using AVHRR Polar Pathfinder datasets, in Proceedings of the IGARSS 2000, 24-28 July 2000, Honolulu, Hawaii, USA. (published in both hard copy and CD-ROM).
- [2]. **Zhang, T.** and R. L. Armstrong, 1999. Passive microwave remote sensing of frozen soils, in Proceedings of the Third International Scientific Conference on the Global Energy and Water Cycle, Jointly with the Fourth Study Conference on GEWEX Asian Monsoon Experiment (GAME), 16-19 June, 1999, Beijing, China, Preprint Volume, Supplementary Collection, pp. 19-21.